Prospects for Dark Matter Searches with Measurements of the Electron Flux with GLAST

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Abstract. We discuss prospects for the LAT detection of signatures from the lightest Kaluza-Klein (LKP) particle of universal extra dimensions. The LKP annihilates directly into e+e- pairs and into other channels that produce energetic e+e-, that may be detectable in the high energy electron flux. We discuss the LAT capability to detect high energy (20 GeV - ~1 TeV) cosmic ray electrons and protons and analyze the LAT sensitivity to LKP-produced electrons and positrons for various particle masses and pair annihilation cross sections rates, including the effect of electrons diffusive propagation in the galaxy.

Keywords: gamma-ray telescope, high energy cosmic ray electrons, astrophysical particle dark matter, Kaluza-Klein dark matter
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INTRODUCTION

A lot of efforts, both in theoretical predictions and experiments, are currently being made in order to identify the nature of particle dark matter. Indirect searches for dark matter consist of the detection of the stable standard model products of dark matter annihilation. The first detection, when it occurs, will certainly be challenged by many speculations for more mundane interpretations, and it therefore should be as un-ambiguous an interpretation as possible. The direct annihilation of dark matter particles into electron-positron pairs would be a very fortunate case, which would result in a clearly identifiable spectral feature in the electron-positron flux. This scenario has been explored in detail in [1]. A very prominent candidate for particle dark matter is the lightest Kaluza-Klein particle (LKP) of universal extra dimensions [2], which is predicted to have a sizable pair annihilation cross section into $e^+ e^-$ pairs, with a branching ratio of ~ 20%. An equally large branching ratio is predicted in this model into muon and tau pairs, again yielding hard electrons after decay. The viable range for the LKP mass starts from ~ 200 GeV up to a few TeV, and detection of electrons (and positrons) at this energy are indeed realistic with current experiments. Also, if the electron spectrum is measured with good accuracy, it can reveal other spectral features corresponding to other modes of dark matter pair annihilation, but their interpretation may be more challenging.

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There are several currently active and planned experiments targeting the detection of WIMP annihilation products, including Pamela (e^+, e^- , p^+, p^-, [3]), BESS (p^+, p^-, [4]), CALET (electrons, [5]), ATIC (electrons, [6]), HESS (_ , electrons, [7]), and others. Search for DM annihilation signatures in cosmic ray antiproton and positron fluxes has been pursued during the last 10 years or more by BESS, HEAT, and Pamela, but recently the attention was also attracted by the possibility to see a DM annihilation feature in the total electron-positron flux [e.g. 1], which allows for a much simpler interpretation. In fact, simple calculations indicate that in order to see the DM-induced spectral bump on top of the "conventional" e+e- flux (the background in this case), with the same confidence as in positron flux (where the background will be the "conventional", presumably secondary positron flux), the instrument should have an effective geometric a factor $F_{particle}$ / $F_{antiparticle}$ larger than an instrument with capability to separate electrons from positrons, which basically is a magnetic spectrometer, a rather complicated instrument with a geometric factor normally limited by the magnetic field size. Hence, in order to have the capability to compete with the currently flying magnetic spectrometer Pamela, the geometric factor of the "conventional" electron spectrometer can be as small as ~ 200 cm^2 sr.

Presently in its final stage before launch, the GLAST-LAT space gamma-ray observatory [8] will be capable to detect high energy electrons in the energy range from 20 GeV to about 1 TeV. LAT is of course not designed to distinguish electrons from positrons, so we refer here to the sum as electrons for simplicity. In this paper we explore the GLAST prospects in the search for astrophysical signatures of particle dark matter annihilations.

LAT CAPABILITY TO DETECT COSMIC RAY ELECTRONS

It has been described elsewhere that LAT, being a _–ray telescope, intrinsically is also an electron detector [9]. LAT has a configurable onboard trigger that accepts and sends to the ground for further analysis all "high energy" events with energy in the calorimeter above 10-20 GeV. We only need to tell the LAT how to discriminate electrons from hadrons, because the main LAT handle in separating photons from hadrons – the Anti-Coincidence Detector, does not help with electrons. A set of analysis cuts has been developed in order to efficiently separate electrons from hadrons with a residual contamination from hadrons smaller than 3% (with respect to the number of detected electrons) in the energy range from 20 GeV to ~ 1 TeV. The effective geometric factor after applying these cuts is ~ 1 m^2 sr and energy resolution (_) is 5-20% depending on the energy. We can compare it with the geometric factor of Pamela which is ~ 0.06 m^2 sr in "calorimeter only" mode, in which it does not determine the particle charge.

As a result, it was demonstrated that the LAT will be able to precisely reconstruct the electron spectrum in the quoted energy range. Extensive work is ongoing with the aim of expanding the energy range in both directions. Our estimates show that the LAT should detect > 10^7 electrons above 20 GeV, and > 2,500 electrons above 500 GeV per year of operation. It is worth mentioning that the official duration of the LAT operation is 5 years, but we expect to operate it for 5 more years. This means that an excellent statistics on high energy electrons, never achieved before, will be collected in this experiment. The very important issue of systematical errors is currently under careful investigation. Figure 1 shows all currently available experimental results on high energy electrons, along with that expected statistics from the LAT for 6 months of operation.

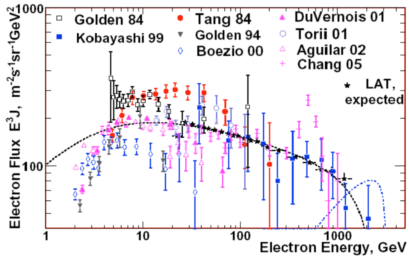

Figure 1. Currently available results on HE electrons, shown along with expected from LAT for 6 months of observations

EXAMPLES OF LAT SENSITIVITY FOR DARK MATTER CANDIDATES

We now apply the LAT capability to detect electrons to dark matter particle indirect detection. This is supposed to be an example, with the goal to let the interested reader to apply the LAT detection sensitivity to any particular dark matter model which predicts the appearance of electrons and positrons. As we already mentioned, the idea is to simulate the LAT response to the expected signal in electron flux from a particular DM model, and to see if this signal can be detected on top of the existing astrophysical background, which obviously is the "conventional" electron flux.

Simulated LAT sensitivity for hypothetical KKDM particle

We simulated the effect of a contribution by a hypothetical LKP particle annihilation according to the scenario given in [1]. According to this model, we simulated the injection of electrons from the annihilation of LKP with masses of 300 GeV and 600 GeV, assuming that 20% of the annihilation occurrences would generate electron-positron pairs [10]. We used a boost factor value of 5, assumed to originate from galactic clumpiness, and a local dark matter density _=0.4 GeV/cm^3. The annihilation process should create a "delta-function"-like spectral line at the energy corresponding to the LKP mass, and this "energy spike" should travel from the origin point through the Galaxy to reach us, undergoing diffusive propagation effects. Because of rapid energy losses due to synchrotron radiation

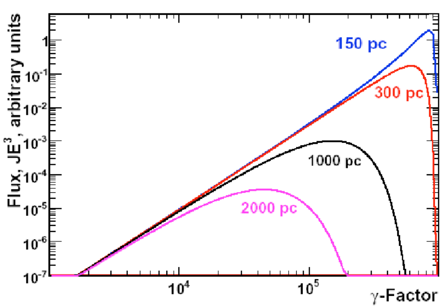

Figure 2. Propagation of the signal from annihilation of LKP with the mass of 500 GeV originated at different distances from Earth

and IC scattering, the shape of the line rapidly transforms during propagation, and illustrated in Fig.2**,** where we plot the simulated spectral shape of the line after propagation. If the uniform distribution of DM clumps is assumed, all the contributions from separate clumps are adding together, and the effect will be seen as a sharp high energy edge from the closest clump.

Our next step was to "conventional" electron spectrum and contribution from LKP annihilation in the simulations of the LAT and see what will be its response. The simulated result for 5 years of LAT observations of high energy cosmic ray electron flux, with added contributions from 300 GeV and 600 GeV heavy LKP within the model being illustrated, is shown in Fig.3. The estimated time needed to detect LKP for this model with 5_ significance is shown in Fig.4.

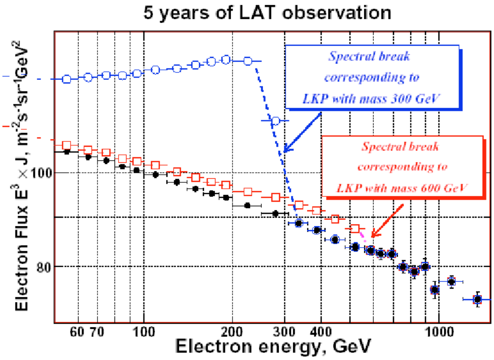

Figure 3. Simulated detection of the signal from LKP with the mass of 300 GeV and 600 GeV for 5 years

More examples of LAT sensitivity to DM signals

We simulated other particle DM models as well, specifically in the context of supersymmetry:

- Model 1: Particle mass 200 GeV, final state b-bar, b. SUSY benchmark, e.g. mSUGRA in bulk or funnel region, bino-like LSP.
- Model 2: Particle mass 200 GeV, final state $\_^+\_^-$. SUSY benchmark, e.g. mSUGRA in stau co-annihilation region, bino-like LSP
- Model 3: Particle mass 400 GeV, final state W^+W^-. SUSY benchmark, e.g. mSUGRA in focus point region, higgsino-like LSP, or minimal anomaly mediation, wino-like LSP
- Model 4: Particle mass 300 GeV, final state UED. 20% branch ratio in each charged lepton flavor, ~7% in up-quarks, plus other SM channels

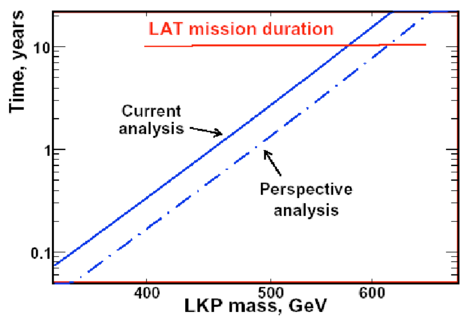

Figure 4. Time needed to detect signal from LKP with given mass with 5_ confidence

- Model 5: Particle mass 300 GeV, final state e^+e^-. This is the most extreme case; similar models proposed in the context of the DM annihilation interpretation of the 511 keV line [11]

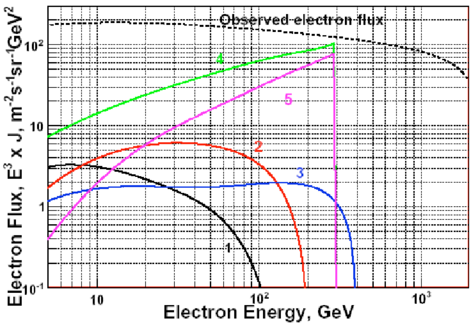

Figure 5. Expected signals from different DM models

Simulated signal in electron flux from these models is shown in Fig.5, assuming boost factor 100 and a smooth halo. Models 4 and 5, where we have direct production of electrons and positrons, look very promising for detection, as expected. Sharp spectral features should be easily recognizable. Models 1-3, with less obvious spectral features, are much more questionable for a clean detection, unless the boost factor is > 1,000. The "conventional" electron flux is shown for comparison. Anyway, assuming large event rates to be collected by LAT for an extended period of observations, there is a realistic hope that these features can be revealed if they exist. This is illustrated in Fig.6, where we give the significance of the edge detection for 3 years of LAT operation with varying the boost factor, for models 4 and 5. It is seen that the signal from DM predicted for these two models can be reliably detected if the boost factor exceeds 10. The shape of the spectrum to be detected within these two model assumptions, is shown in Fig. 7.

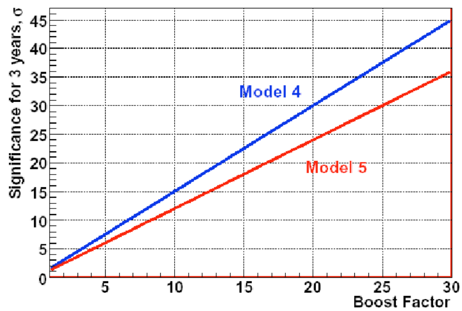

Figure 6. Signal detection significance for models 4 and 5 for 3 years of LAT operation

SUMMARY

It has been demonstrated elsewhere that the LAT detector onboard GLAST will be able to detect high energy electrons in the energy range from 20 GeV to ~ 1 TeV with 5-20% energy resolution and high statistics. We explored several viable scenarios of how LAT might

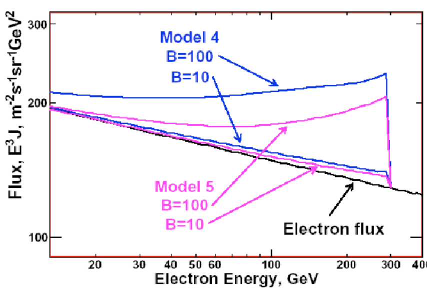

Figure 7. Electron flux expected from models 4 and 5, shown along with "conventional" electron flux

observe dark matter, when the spectral feature is predicted to be observed in the high energy electron flux. If there is a dark matter-induced feature in the high energy electron spectrum in the range 20 GeV – 1 TeV, LAT will be the best current instrument to observe it with high statistical confidence.

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